NORTHERN ILLINOIS UNIVERSITY

A proposal for research to determine the spatial and temporal relationships of the Palawan microcontinental block and the islands of Mindoro and Panay, Palawan-Central Philippine collision zone

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By

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Capstone Approval Page

A proposal for research to determine the spatial and temporal relationships of the Palawan microcontinental block and the islands of Mindoro and Panay, Palawan-Central Philippine collision zone

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ABSTRACT (100-200 WORDS): There currently exists contradictory theories as to where and when the collision between the Palawan microcontinental block and the Philippine Mobile Belt initiated. The working hypothesis of the project is that the tectonic boundaries initially suggested have been incorrectly inferred and instead lie between the islands of Palawan and Mindoro in a subduction-related thrust zone; the Palawan-Central Philippine collision zone. Presented is a proposal modeled after National Science Foundation (NSF) guidelines for a marine 2D seismic survey to determine these relationships in the Mindoro Straight between the islands of Palawan and Mindoro in the continental-arc system. The proposal is meant to serve a vital role in preparation of graduate research at the doctorate level for Megan L. Saunders.

Research to determine spatial and temporal relationships of the Palawan microcontinental block and the island of Mindoro, Palawan-Central Philippine collision zone

PROJECT SUMMARY

Currently there exists a debated theory regarding the development of the Palawan-Central Philippine collision zone. The model presented by Hamilton (1979) states that the collision between the Palawan microcontinental block and the Philippine Mobile Belt (PMB; Gervasio, 1966) occurred during the Miocene. This model was further developed by Taylor and Hayes (1980), Holloway (1982), McCabe et al. (1982, 1985), Aurelio (2000), Zamoras et al. (2004, 2008), Queãno et al., (2009), Suzuki et al. (2000), Yumul et al. (2000, 2003), Karig (1983), and Sarewitz and Karig (1986). According to Holloway (1982) the collision resulted form the south-southeast movement of the Palawan microcontinental block toward the northwest movement of the PMB. Holloway (1982) also suggested that Palawan separated from the Asian mainland beginning as early as the Paleocene, a movement which led to seafloor spreading of the South China Sea plate until the Oligocene. Using ophiolite and metamorphic rock groups as well as marine magnetic modeling Yumul et al. (2005) and Dimalanta and Yumul (2004) these rocks, found in Mindoro, Panay, and the Romblon Islands are the northeastern boundary of the Palawan microcontinental block. Based on the lack of subsurface data to analyze it is suggested that to determine the debated boundaries between the islands of Palawan and Mindoro a marine active source 2D seismic survey be completed in the Mindoro Straight. Although most researchers agree on the timing of collision as Miocene, most disagree as to where the collision actually initiated (Pineda and Aurelio, 1992; Faure et al., 1989).

The research vessel chosen for this project is well equipped with state of the art geophysical instruments that will be implemented during the project. These include paleomagnetic, bathymetric, and gravitational anomaly instruments (IAGC and OGP, 2011).

The working hypothesis of the project is that the tectonic boundaries initially suggested have been incorrectly inferred and instead lie between Palawan and Mindoro. It is also predicted that a subduction-related thrust zone exists in the proposed study area and is thus the basis for the identification of the Palawan-Central Philippine collision zone. By conducting a marine active source 2D seismic survey to image the upper crust at the proposed boundary reliable constraints can be drawn on these tectonic relationships, thus shedding light on the greater tectonic development of the Philippine archipelago.

The **intellectual merit of the proposed activity** is that it will further define the important tectonic relationships between the Palawan microcontinental block and the islands of Mindoro in the Central Philippines. Identification of the tectonic boundaries will undoubtedly add to the current knowledge and data sets, and attempt to create a larger understanding of the complex geometries found in island arc-continental collision zones.

The **broader impacts of the proposed activity** is that the project will provide continued training in geophysical data processing and analysis for both graduate and undergraduate students at Northern Illinois University (NIU) interested in structure, tectonics, and/or geophysics. The project will provide a PhD research project for Megan Saunders in the Department of Geology and Environmental Geosciences at NIU. Information gathered from the research will be made available in open resource databases such as the National Oceanic and Atmospheric Administration (NOAA) as well as publications in various scientific journals. Presentations will be conducted in at least one conference including, but not limited to the annual meeting of the Geological Society of America, the American Geophysical Union, and the Seismological Society of America.

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PROJECT INTRODUCTION AND OVERVIEW

The Palawan-Central Philippine collision zone is believed to be the result of the collision between the Palawan microcontinental block with the Philippine Mobile Belt (PMB; Gervasio, 1966) in the Miocene (Taylor and Hayes, 1980; Holloway, 1982; McCabe et al., 1982, 1985; Aurelio, 2000; Zamoras et al., 2004, 2008; Queãno et al., 2009; Suzuki et al., 2000; Yumul et al., 2000, 2003; Karig, 1983; Sarewitz and Karig, 1986). Focal mechanism solutions along the southern portion of the Manila Trench near the island of Mindoro in the western Philippine island arc show a steeply dipping subducted slab (Cardwell et al., 1980). According to Yumul et al. (2000), Karig (1983), Queãno et al. (2009), and Sarewitz and Karig (1986) the relationship between the Palawan microcontinent and Mindoro is either by subduction-related foreland thrust or by large-scale strike-slip motion in the early Miocene. Tectonic reconstructions done by Hashimoto (1978b) show the geometric relationship between Palawan and Mindoro as one of strike-slip motion resulting from the northwestern movement of the western portion of the Philippines along the Visayan Dislocation Line during the Miocene. However, based on more recent research (Marchadier and Rangin, 1990; Barrier et al., 1991; Queãno et al., 2009; Zamoras et al., 2004, 2008; Suzuki et al., 2000) it is hypothesized that the original assumptions of Hashimoto (1978a, 1978b) are incorrect and that the seismic data collected during this project will support the second school of thought, that an extinct subduction-related thrust belt currently exists between Palawan and Mindoro in the Mindoro Straight.

Since first identified by Hamilton (1979) the PMB has been the topic of much research. The collision with the Palawan microcontinental block in the Miocene caused large amounts of deformation resulting in on-land emplacement of ophiolite suites, melanges, and multiple metamorphic belts throughout the Palawan-Central Philippine collision zone. Since most researchers agree on the Miocene (i.e. Yumul et al., 2000; Holloway, 1982; Karig, 1983; Sarewitz and Karig, 1986) as the active age of collision the focus of this project will be on determining the geometric relationships in the continental-arc system since the spatial relationships remain enigmatic. An in-depth analysis is essential to determine where collision initiated. To determine these important relationships it is proposed that a marine active source 2D seismic survey be conducted in the Mindoro Straight between the islands of Palawan and Mindoro.

The working hypothesis of the project is that the tectonic boundaries initially suggested by Hashimoto (1978) were incorrectly inferred. By conducting a marine active source 2D seismic survey to image the upper crust at the proposed boundary reliable constraints can be drawn on these tectonic relationships, thus shedding light on the greater tectonic development of the Philippine archipelago. It is expected that evaluation of the seismic data will support the assumptions of Marchadier and Rangin (1990), Barrier et al. (1991), and Queãno et al. (2009) with reliable data showing that the tectonic boundary lies between Palawan and Mindoro rather than to the northeast of Mindoro as Hashimoto (1978a, 1978b) Yumul et al. (2000, 2003, 2005), and Dimalanta and Yumul (2004) have placed it. It is predicted that a subduction-related thrust zone exists in the proposed study area and is thus the basis for the identification of the Palawan-Central Philippine collision zone.

GOALS AND OBJECTIVES

The overall objective of this proposal is to contribute to the fundamental understanding of the development of the tectonic relationships between the Palawan microcontinental block and the Philippine island arc. It is proposed that an active source seismic survey will be the most beneficial analytical method to use to examine the upper crustal geometries in the Mindoro Straight between the islands of Palawan and Mindoro.

It is hypothesized that the proposed research will identify 1) that Palawan collided with the Manila Trench to the northwest of Mindoro causing convex to the east indentation of the Central Philippines, 2) continued southeast motion of the Palawan microcontinental block during the Miocene resulted in left-lateral strike slip motion between Palawan and Mindoro in the Mindoro Straight, and 3) that the current northwestward movement of the Philippine island arc is causing the Palawan microcontinent to cause rotations of the island in the vicinity of the collision zone. Each of the three objectives listed highlights a portion of the geology that remains enigmatic or unproven in the Palawan-Central Philippine collision zone.

There are two main acquisition goals of this project. The most important goal of the project is to complete a marine 2D seismic survey. The second goal involves three separate geophysical surveys running concurrently with the seismic survey. The research vessel chosen for the project is equipped with paleomagnetic, bathymetric, and gravity anomaly instruments (LDEO, 2011). Due to the operating costs of the research vessel it is in the best interest of the scientific community that these three surveys be conducted while the research team is primarily concerned with the 2D seismic survey.

Goal 1: Marine 2D seismic survey

The most significant goal of this project is to utilize a towed marine 2D seismic survey to create profiles to map the upper crust with the aim of identifying the thrust zone suggested by Marchadier and Rangin (1990), Barrier et al. (1991), Queãno et al. (2009). The 2D seismic survey will allow for the interpretation of the subsurface in the Mindoro Straight so that a complete cross-section can be made. There are currently two cross-sections available. Suzuki et al. (2000) attempted a cross-section meant to explain folding patterns of central to northeastern Palawan based on ophiolite assemblages incurred during subduction in the Paleo-Palawan Trench, however, the cross-section is incomplete and based on general relationships rather than definite structural data as determined from seismic interpretation.

Goal 2: Paleomagnetic, bathymetric, and gravity surveys

The Research Vessel Marcus G. Langseth (owned by NSF and operated by the Lamont-Doherty Earth Observatory (LDEO) at Columbia University) is equipped with excellent state of the art geophysical equipment such as a Bell BGM-3 Gravimeter, a Geometrics 882 Magnetometer, and a Knudsen 3260 Echosounder. Although the focus of the project is the 2D seismic survey, the research these instruments will allow cannot be passed by. Due to the price of the vessel it makes more sense to complete all four surveys at one time, thus gathering the most data possible.

Paleomagnetic data is important to the project since it could lend additional identification of the direction of movement of the Palawan microcontinental block prior to the collision with

Mindoro, which are essential to understanding the tectonic development of the collision zone. Acquisition of paleomagnetic data has yet to be accomplished in the study area. Due to the expected chaotic nature of rocks in the collision zone the paleomagnetic data will inevitably be the most difficult to process and interpret.

A bathymetric survey will be done by scanning sonar using the Knudsen 3260 Echosounder. Currently there is a lack of bathymetric data in the Mindoro Straight (GEBCO; NOAA). High resolution bathymetric data will inevitably help with the 2D seismic interpretations and cross-section as well as adding to databases such as NOAA to aid in future research.

The research vessel Marcus G. Langseth is pre-equipped with not only seismic, magnetic, and sonar instruments, it also sustains a Bell BGM-3 Gravimeter (LDEO, 2011; *see Facilities, Equipment, and Other Resources* for vessel specifications).

SIGNIFICANCE

The scientific significance of this project is that since the geometries of the Palawan-Central Philippine collision zone are not fully understood, completing a project that will identify the relationships between the Palawan microcontinental block and the adjacent island of Mindoro will allow researchers to draw conclusions that will add to the developing knowledge of continental-arc systems.

METHODOLOGY

The approach of the project is to use a marine 2D seismic survey in order to cover the size of the study area. A 2D seismic survey has four major benefits over a 3D survey. First, according to the International Association of Geophysical Contractors (IAGC) 2D acquisition also allows for larger survey areas due to the typical separation of sail lines. Second, in a 2D seismic survey the reflections from the subsurface lie directly below the sail line, thus creating the two dimensions (horizontal and vertical; Fig. 1). In a typical 3D seismic line multiple streamers are pulled behind the research vessel, but in a 2D survey as little as a single streamer can be implemented. For simplicity this project will utilize a single streamer. Third, diminishing the amount of data collected

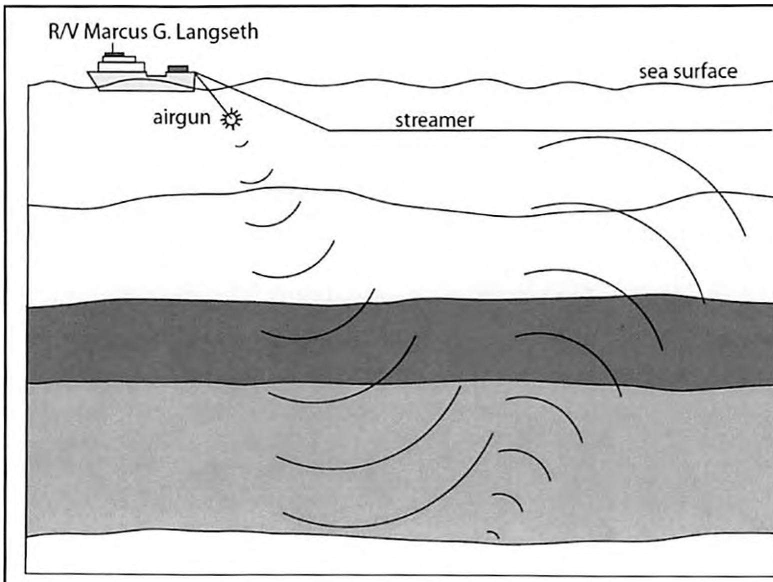

Figure 1. Representation of a marine 2D seismic survey setup showing a towed streamer (*after* LDEO, 2011).

allows for less complicated analysis and processing (IAGC and OGP, 2011). Finally, streamer feathering is less crucial in a 2D seismic survey than in 3D surveys. (Streamer feathering is the lateral deviation of the towed streamer from the ship sail line (IAGC, 2011).) Since the reflections are expected to lie directly below the streamer, lateral deviation has less significance in 2D seismic interpretations.

The weakness of a 2D seismic survey lies in the gap in knowledge caused by the large spacing between sail lines (IAGC, 2011). Typically the lines are not much closer than one or two kilometers, so interpretation of the sub-surface between sail lines can be troublesome (IAGC, 2011). Although 3D surveys show a more sophisticated and detailed image of the subsurface, they are limited to an area of approximately 3,000 km^2 for the largest surveys (IAGC, 2011).

Using the NSF owned research vessel R/V Marcus G. Langseth (LDEO, 2011) this project will cover an area of approximately 12,000 km^2. The vessel is equipped with all acquisition equipment necessary for the project including source (airgun) arrays, four 6 km solid-state hydrophone streamer cables, a 2000 psi sound source array towed in four "strings" that can be configured in the desired 2D source array, a gravitometer and an magnetometer (LDEO, 2011; *see Facilities, Equipment, and Other Resources* for vessel specifications).

GEOLOGIC SETTING

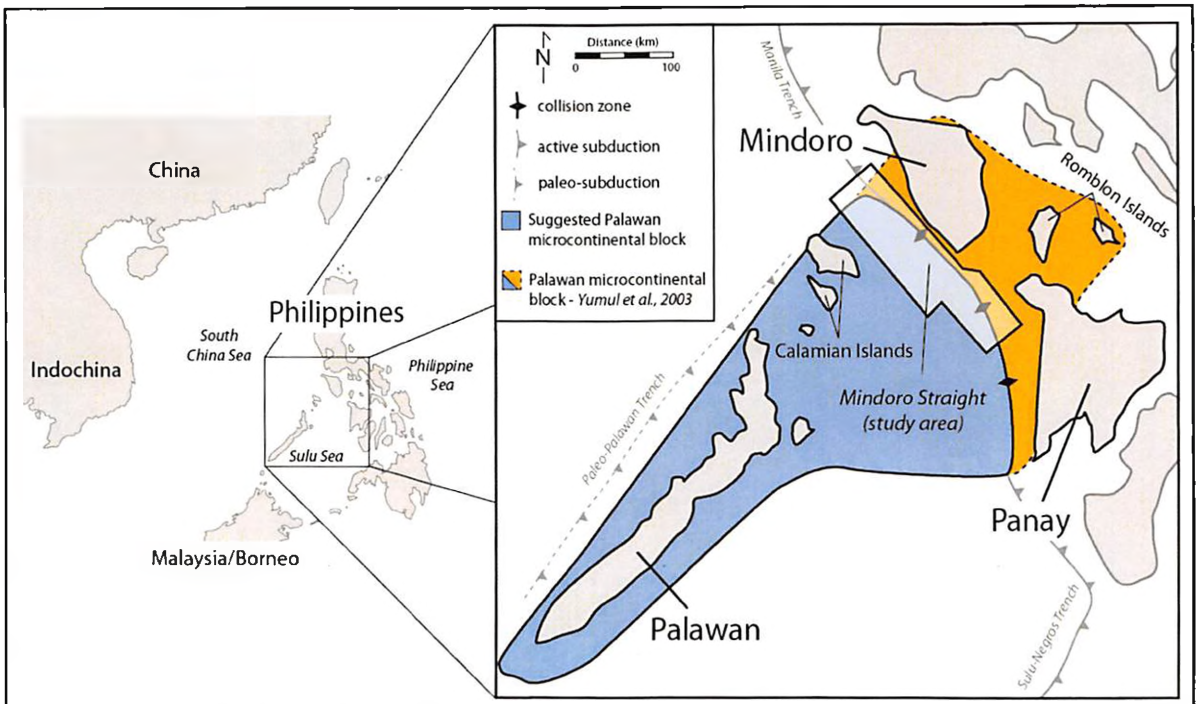

Figure 2. Map of the suggested Palawan-Central Philippine collision zone. Shown in blue is the suggested Palawan microcontinental block. Orange represents the northern boundary of the Palawan microcontinental block as proposed by Zamoras and Matsuoka (2004, 2008), Yumul et al. (2003), Holloway (1982), Hamilton (1979), and Hashimoto (1978).

Stresses generated within the Philippine island arc system are dominantly accommodated by the discontinuous east-dipping Manila-Negros-Sulu-Cotabato trench system to the west, the west-dipping East Luzon Trough-Philippine trench system to the east, and the centrally positioned left-lateral Philippine Fault (Yumul et al,. 2000, 2003; Queaño et al., 2009; Macpherson, 2008; Barrier et al., 1991; Roeder, 1977). According to Rangin et al. (1999) there is no active spreading center in the surrounding area, thus the ongoing subduction and collisional processes are responses to regional interaction of geological events such as the northwestward motion of the Philippine island arc as identified by Holloway (1982).

Two major tectonic regions compose the Philippines: the seismically active PMB and the aseismic Palawan microcontinental block (Gervasio, 1971; Queaño et al., 2009). The latter is proposed to have rifted from the Eurasian plate as a result of the opening of the South China Sea plate in the early Oligocene to early Miocene (Taylor and Hayes, 1980; Holloway, 1982; Ru and Pigott, 1986) and began colliding with the PMB during the middle Miocene (Yumul et al., 2003; Suzuki et al., 2000; Hashimoto, 1978b). Faure et al. (1989) noted that the collision zone is located along western Mindoro and is believed to be the site of collision between the Palawan block and the PMB, however, the exact placement of collision is unknown and therefore subject to controversy, whether it is west of Mindoro, along central Mindoro, or west of Romblon to the east of Mindoro (Fig. 2).

There seems to be a general understanding of the processes that led to the development of Palawan (discussed below) yet the site of its collision with the Philippine island arc remains controversial (Pineda and Aurelio, 1992). Suzuki et al. (2000) suggested that Palawan collided with the Manila Trench to the northwest of Mindoro.

Palawan Provenance

The majority of the studies to determine the age of Palawan and therefore the Palawan-Central Philippine collision zone have been based on paleontology (Hashimoto, 1978a, 1978b; Fuller et al., 1991), and land studies of ophiolites suites and metamorphic folding (Queaño et al., 2009; Barretto et al., 2000; De Jesus et al., 2000; Suzuki et al., 2000; Yumul et al., 2000, 2003; Zamoras et al., 2004, 2008; Holloway, 1982). Still, no seismic data exists to justify the many structural and stratigraphic relationships expected in the area.

In an attempt to validate the hypothesis that Palawan has Asian mainland provenance Suzuki et al. (2000) completed the most thorough petrological study on sandstones in successions in northern Palawan and attempted to match them with rocks from Kwangtung and Fukien, regions on the southeast coast of China. This portion of Palawan contains Permian limestones, Permian and Triassic chert, sandstone and basaltic rock set in a mudstone matrix (Suzuki et al., 2000). Dissimilarly, central and southern Palawan are composed of ophiolites consisting of peridotites, gabbros, basalts, and associated sedimentary rocks (Hamilton, 1979; Raschka et al., 1985). Although these ophiolites may aid in the overall understanding of the tectonic evolution of the Palawan microcontinental block, they are not interpreted to be vital to the proposed research in the Mindoro Straight. However, the lithologies of the northern portion of Palawan are critical to the knowledge of when and where Palawan collided with the PMB.

Suzuki et al. (2000) concluded that the lithologies of Kwangtung and Fukien match those that comprise the sandstones in Palawan. Further, Suzuki et al. (2000) determined that clasts of

Upper Cretaceous to Eocene sedimentary successions in Central Palawan are derived from the southern China continental block. Suzuki et al. (2000) also concluded that the age of the Palawan sandstones agree with the time that the Jurassic to Cretaceous granites of southern China were eroded, thus depositing clasts and sediments to the South China Sea basin. The sediments that compose the northern portion of Palawan are from continental sources on the Asian mainland. Northeast-southwest spreading during early Oligocene to early Miocene (Taylor and Hayes, 1980; Holloway, 1982) pushed Palawan southeastward toward the newly forming Philippine island arc. Suzuki et al. (2000) suggests that due to westward movement of the Philippine island arc system the Palawan microcontinental block began to subduct into the Manila Trench, which at this time was a continuous trench with the Sulu-Negros Trench. By the very nature of subduction it can be expected that the initial site of collision is long gone. However, it can be argued that due to continued collision evidence of deformation in the subsurface as shown by seismic reflections will allow for tectonic reconstructions of the study area. It is hoped that these tectonic reconstructions will identify the exact location of collision.

Other studies have been completed to prove the theory of Asian mainland provenance. Queaño et al. (2009) determined, based on paleomagnetic data in Luzon (northern Philippines), that the Palawan microcontinental block was indeed transported southeast from China. McCabe et al. (1985), Rangin et al. (1985), and Jumawan et al. (1994) all conclude that the collision emplaced ophiolite suites throughout the Central Philippines.

Interpretations of geophysical data from ophiolites in Mindoro led to an important discovery by Yumul et al. (2003), which suggested that the collisional boundary lies between Mindoro and the Romblon Islands (Fig. 2). The problem is that ophiolites on land by nature are disorderly, leading to potentially large uncertainties. Such a conclusion highlights that there must be several collision zones involving various fragments of oceanic lithospheres and metamorphic rocks within the Palawan-Central Philippine collision zone.

It is necessary to mention the cessation of spreading in the South China Sea plate. Many have suggested the completion of spreading in the early Miocene (Suzuki et al., 2000; Taylor and Hayes, 1980; Holloway, 1982). Although spreading in the South China Sea plate is believed to have ended, westward movement of the Philippine island arc continues. Since it seems that the Palawan microcontinental block remains locked, the Philippine island arc is now responsible for the continued collision (Suzuki et al., 2000).

Paleomagnetics

The method used most often to determine the relationships in the Palawan-Central Philippine collision zone has been paleomagnetics of ophiolite suites and melanges (Queaño et al., 2009; Barretto et al., 2000; De Jesus et al., 2000; Suzuki et al., 2000; Yumul et al., 2000, 2003; Zamoras et al., 2004, 2008; Holloway, 1982). There are some obvious problems with using ophiolites and melanges in paleomagnetic surveys. First, melanges are chaotically mixed assemblages of rock consisting of brecciated blocks in a highly sheared matrix (Boggs, 2006, p. 563). Second, ophiolite emplacement onto continental crust is the result of thrusting and collision, (Van Der Pluijm and Marshak, 2004, p. 342) again a chaotic process. Although, when found in place, these rock assemblages can be very helpful to tectonophysicists interested in determining paleo-plate movement. In the Palawan-Central Philippine collision zone these rocks are prevalent, which has led to many contradictory conclusions being drawn.

One of those conclusions is that the collision caused rotations of the islands in the Central Philippines. Land magnetic surveys have been used to show these rotations not only in the Central Philippine islands, but also to the north in Luzon (Queaño et al., 2009). This study showed that no reliable paleomagnetic data has ever been recorded from the Ophiolites and thus theirs is the only study with dependable data. Queaño et al. (2009) shows that Luzon, which sits at the northern most portion of the PMB, experienced enough deformation during the Cenezoic that determination of rotation is unlikely at this time.

Yumul et al. (2000) suggested that the island of Panay rotated clockwise as a result of the collision. According to the study, paleomagnetic results show that during the Miocene Mindoro also rotated counterclockwise, in opposite motion to the rotation of Panay just to the southeast of the island. This study shows the cogwheel nature of the islands in the Central Philippines. Based on this study it is suggested that the boundary between Palawan and the Central Philippines must lie somewhere in the Mindoro Straight. It is also suggested that the Palawan microcontinental block is stronger and more rigid than the islands of Mindoro and Panay otherwise it would have experienced higher degrees of deformation from the westward motion of the Philippine island arc. With continued collision it is possible that the Palawan microcontinental block may even slice through the central region of the Philippines displacing islands to either side, eventually reaching the Philippine Sea plate to the east.

One of the most recent studies of the Palawan-Central Philippine collision zone agreed with Zamoras and Matsuoka (2004), Yumul et al. (2003), Holloway (1982), Hamilton (1979), and Hashimoto (1978a, 1978b) by stating that the collision zone lies between the Buruanga Peninsula in northwest Panay and the Romblon Islands.

The most thorough structural study thus far was completed on the Calamian Islands situated between Palawan and Mindoro in the Mindoro Straight and to the southwest of the study area (Zamoras and Matsuoka, 2004; Fig. 2). Between the Calamian Islands and southwest Mindoro runs the southern extent of the Manila Trench (Holloway, 1982). It is suggested that during the counter-clockwise rotation of Mindoro in the Miocene a rift developed, which Holloway (1982) identified as the Calamian-southwest Mindoro rift. Zamoras and Matsuoka (2004) identified that the area between the Calamian Islands and Mindoro must be the site of this rupture in the Miocene. They also conclude that this is now the site of intense compression and eventually the paleo-rift zone will close, eluding to the northwestern motion of the Philippine island arc as identified by Holloway (1982). Based on Holloway's (1982) and Zamoras and Matsuoka (2004) it was again determined that a paleomagnetic survey in the Mindoro Straight would be beneficial if a paleo-rift zone does indeed exist in the area.

One problem remains, if collision initiated at Mindoro, where are the scars? Yumul et al. (2003) found no stratigraphic or structural evidence of a foreland thrust belt on southwest Mindoro. Although the study agrees that Mindoro is the site of collision, there seems to be an absence of a so-called smoking gun. Again, there is no agreement on where the collision occurred (Pineda and Aruelio, 1992). Having a definite seismic image of the sub-surface will, if nothing else, put to rest the controversy of Mindoro being the site of collision.

RESEARCH PLAN

From reading previous work it is clear that there are many opinions of where the collision zone is exactly located as well as what methods would be most beneficial to determine these relationships. Utilizing the research vessel Marcus G. Langseth allows us to gather as much data as we possibly can to aid in this problem. Until an advisor can be assigned, it is expected that the PhD student will be the only researcher from NIU aboard the vessel. The Langseth carries a 20 person operating crew and 35 scientific personnel, more than enough to conduct four consecutive geophysical surveys.

Due to the nature of the research the LDEO employs a project planner to aid primary investigators (LDEO, 2009). It is suggested that research take place during the sunny months of January and February. The vessel will be at sea for 31 days, stopping only for regular maintenance. Planning a traverse will be difficult in the Mindoro Straight due to the large amount of human activity such as fishing and shipping. The problems to be expected as a result from other boat activity can slow or even stop research. The streamer length is variable, approximately 25 km to 40 km. Therefore, advance research notice to fisherman, fishing companies, and shipping companies must be given. The vessel also comes equipped with "birds" which can sink streamers deep enough to allow a boat to pass safely over without damaging the equipment in an emergency (LDEO and ODP, 2011). It is suggested, but not required, that a smaller lookout boat be employed to aid in the protection of the streamer.

Just as difficult to maneuver are the bathymetric highs and reef protection areas. Since little high-resolution bathymetry data exists in the Mindoro Straight it will be difficult to plan an effective traverse. In this respect the crew and researchers must be flexible and therefore vigilant in record keeping. Luckily, the vessel has unparalleled GPS and other monitoring systems. One can even track the vessel's path on the LDEO's website.

Another concern in planning a traverse is large marine mammal activity. There is no expectation of damaging marine mammals with the airgun arrays used in these types of seismic surveys, however it can happen. Depending on the country of operations and the area-specific environmental controls in place, a visual watch for marine mammals from the vessel may be ongoing for at least 30 to 60 minutes before the source is first activated. On some surveys, dedicated acoustic monitoring methods may additionally be utilized to identify the presence of marine mammals within the vicinity of the source array. It is only when the crew has been informed that no marine mammals are present that the source can be activated and data acquisition can proceed (LDEO and OGP, 2011).

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SUMMARY PROPOSAL BUDGET — **YEAR 1**

ORGANIZATION: **Northern Illinois University**				PROPOSAL NO.	FOR NSF USE ONLY — DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: **N/A**				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co.-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR		Funds Requested by Proposer	Funds Granted By NSF (If Different)
1 N/A	0.0	0.0	0.0		0	
2	0.0	0.0	0.0			
3	0.0	0.0	0.0			
4	0.0	0.0	0.0			
5	0.0	0.0	0.0			
6 (0) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	0.0	0.0	0.0			
7 (0) TOTAL SENIOR PERSONNEL (1-6)	0.0	0.0	0.0		0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1 (0) POST DOCTORAL ASSOCIATES	0.0	0.0	0.0		0	
2 (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					0	
3 (1) GRADUATE STUDENTS					16,800	
4 (0) UNDERGRADUATE STUDENTS					0	
5 (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					0	
6 (0) OTHER					0	
TOTAL SALARIES AND WAGES (A + B)					16,800	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					773	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)					17,573	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
R/V Marcus G. Langseth		$ 465,000				
TOTAL EQUIPMENT					465,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)					0	
2. FOREIGN					3,267	
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS $ 0						
2. TRAVEL 0						
3. SUBSISTENCE 0						
4. OTHER 0						
( ) TOTAL PARTICIPANT COSTS					0	
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES					0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					0	
3. CONSULTANT SERVICES					0	
4. COMPUTER SERVICES					0	
5. SUBAWARDS	Amount subject to Indirect:		$0		0	
6. OTHER — Sum of all other Direct Costs, NOT tuition = 0	Tuition =		8,028		8,028	
TOTAL OTHER DIRECT COSTS					8,028	
H. TOTAL DIRECT COSTS (A THROUGH G)					493,868	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) — 48.0% Modified Total Direct Costs						
TOTAL INDIRECT COSTS (F&A)	Base Amount:		$20,840		10,003	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					503,871	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)					0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)					503,871	
M. COST SHARING: PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD TYPED NAME & SIGNATURE*	DATE		FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION			
ORG. REP. TYPED NAME & SIGNATURE*	DATE		Date Checked		Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) Supersedes All Previous Editions

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

SUMMARY **YEAR 2**

PROPOSAL BUDGET

				FOR NSF USE ONLY		
ORGANIZATION **Northern Illinois University**				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR **N/A**				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co.-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR		Funds Requested by Proposer	Funds Granted By NSF (If Different)
1 N/A	0.0	0.0	0.0		0	
2	0.0	0.0	0.0			
3	0.0	0.0	0.0			
4	0.0	0.0	0.0			
5	0.0	0.0	0.0			
6 (0) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	0.0	0.0	0.0			
7 (0) TOTAL SENIOR PERSONNEL (1-6)	0.0	0.0	0.0		0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1 (0) POST DOCTORAL ASSOCIATES	0.0	0.0	0.0		0	
2 (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					0	
3 (1) GRADUATE STUDENTS					16,800	
4 (0) UNDERGRADUATE STUDENTS					0	
5 (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					0	
6 (0) OTHER					0	
TOTAL SALARIES AND WAGES (A + B)					16,800	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					773	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)					17,573	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT					0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)					1,519	
2. FOREIGN					0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0						
( ) TOTAL PARTICIPANT COSTS					0	
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES					0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					0	
3. CONSULTANT SERVICES					0	
4. COMPUTER SERVICES					0	
5. SUBAWARDS	Amount subject to Indirect:		$0		0	
6. OTHER Sum of all other Direct Costs, NOT tuition = 0	Tuition =		8,430		8,430	
TOTAL OTHER DIRECT COSTS					8,430	
H. TOTAL DIRECT COSTS (A THROUGH G)					27,522	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 48.0% Modified Total Direct Costs						
TOTAL INDIRECT COSTS (F&A)	Base Amount:		$19,092		9,164	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					36,686	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)					0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)					36,686	

M. COST SHARING: PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $			
PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) Supersedes All Previous Editions

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

SUMMARY
PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Northern Illinois University

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR
N/A

A. SENIOR PERSONNEL: PI/PD, Co.-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested by Proposer	Funds Granted By NSF (If Different)
1 N/A	0.0	0.0	0.0	0	
2	0.0	0.0	0.0		
3	0.0	0.0	0.0		
4	0.0	0.0	0.0		
5	0.0	0.0	0.0		
6 (0) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	0.0	0.0	0.0		
7 (0) TOTAL SENIOR PERSONNEL (1-6)	0.0	0.0	0.0	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1 (0) POST DOCTORAL ASSOCIATES	0.0	0.0	0.0	0	
2 (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				0	
3 (1) GRADUATE STUDENTS				33,600	
4 (0) UNDERGRADUATE STUDENTS				0	
5 (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6 (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				33,600	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				1,546	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				35,146	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) R/V Marcus G. Langseth $ 465,000					
TOTAL EQUIPMENT				465,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,519	
2. FOREIGN				3,267	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
( ) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS Amount subject to Indirect: $0				0	
6. OTHER Sum of all other Direct Costs, NOT tuition = 0 Tuition = 16,458				16,458	
TOTAL OTHER DIRECT COSTS				16,458	
H. TOTAL DIRECT COSTS (A THROUGH G)				521,390	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 48.0% Modified Total Direct Costs TOTAL INDIRECT COSTS (F&A) Base Amount: $39,932				19,167	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				540,557	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				540,557	

M. COST SHARING: PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

BUDGET JUSTIFICATION

Salaries

PI and Co-PIs: No salary is requested at this time.

PhD student: Megan Saunders will be a PhD student in the Geology and Environmental Geosciences department during the project. This research project will be her PhD dissertation. The amount requested is for a full time research assistantship under her advisor. She will focus on seismic processing and reflection interpretation. It is expected that one or more MS students from the Geology and Environmental Geosciences department at NIU will receive a research assistantship for this project. At least one undergraduate will also join the project, while completing undergraduate research. Funding for MS and undergraduate students are not included in the budget at this time.

Equipment

Funds are requested for the use of the Research Vessel Marcus G. Langseth and a marine magnetometer system (see text for description of requested equipment). The cost of the R/V Marcus G. Langseth is $15,000 per day for 31 days, totaling $465,000. The R/V Marcus G. Langseth is equipped with an active source seismic array, hydrophone streamers, a scanning sonar system to be used for bathymetric data acquisition, a gravitometer, and a magnetometer.

Employee Travel

Travel funds requested are for one meeting per year for the PhD student in year 2. Travel will include one person on a US carrier (estimated at $600), hotel ($100/night for 6 nights), registration (student registration of approximately $109), and per diem ($35/day for 6 days).

Travel funds are also requested for travel to the Philippines once during the first year. The travel will include one person. Budget includes airfare on a US carrier from Chicago to Manila, Philippines ($1286), per diem ($35/day for 35 days), one hotel room ($153.95/night for four nights), and taxi ($35/day while in Manila). These costs are based upon estimates from online travel advisors such as travelocity.com and hotels.com.

Other

Requested are also funds to cover tuition for the PhD student.

Facilities and Administrative Costs

These costs are charged as a percentage of the modified total direct costs at a rate of 48.0% (as of July 26, 2011).

FACILITIES, EQUIPMENT, AND OTHER RESOURCES

RESEARCH VESSEL (LDEO, 2011)

The R/V Marcus G. Langseth is a 235 ft long, 3834 gross ton research vessel that is owned by the National Science Foundation and operated by Lamont-Doherty Earth Observatory of Columbia University. Originally constructed as a seismic vessel the Langseth was acquired in 2004, modified, and outfitted to perform the tasks required of a general purpose research vessel.

Particularly unique to the academic research vessel are the Marcus Langseth's extensive geophysical capabilites which include a Simrad 1x1 degree deep ocean multibeam swath bottom mapping system, Syntrak 960-24 seismic recording system with four 6km solid-state hydrophone streamer cable and a 2000 psi, 40 pneumatic sound source array towed in four " strings" that can be configured either as a single, 2D source or dual, alternating 3D source arrays..

Science Equipment

MCS Acquisition	Syntrak 960-24 SSI Seisnet active tape emulation
Hydrophone arrays	Sentry solid cable 12.5 meter groups 150m sections up to four towed separation 50 - 200 meters
Source Arrays	4 x 10 gun strings 9 active, one spare / string 15 meter string length 1650 cu. In. per string
Source Controller	DigiShot
MCS QC	Syntrak SeisNet ProMaxx Focus SIOSeis
Multibeam / Echsounder	Kongsberg EM122 1° x 1° Knudsen 3260 Echosounder
Marine Mammals Observation / Mitigation	Passive Acoustic Monitoring Streamer 2 x Fujinon Big Eye Binoculars
General	Bell BGM-3 Gravimeter Geometrics 882 Magnetometer

Specifications

Built:	1991	**Speed Cruising:**	11kts
Yard Built:	Ulstein (Norway)	**Speed Full:**	13kts
Length (LOA)	71.5m / 235 ft	**Speed working:**	0-11 kts
Beam(moulded):	17.0m / 56 ft	**Endurance**	Job dependent

Draft(max):	5.9m/ 19.5ft	**Range**	13,500 nm
Gross Tonnage:	3834	**Fuel capacity**	1340m3 (353760 gal)
Lightship Displacement:	2578.4	**Fuel Type;**	Marine Gas Oil
Crew	20	**Bollard Pull**	86.2 mt
Scientific Personnel:	35	**Laboratory, existing:**	
Call Sign	WDC6698	**Seismic Lab**	218 m2/ 2345 ft2
IMO Number;	9010137	**Other labs**	
Registration:	NY3360FG	**Main Dk Stbd Dry Lab**	53 m2/570 ft2
		Main Dk Stbd Wet Lab	57 m2/613 ft2
		Main Deck Pt Dry Lab	54 m2/ 581 ft2
		A-Deck Fwd Dry Lab	22 m2/ 237 ft2
		A-Deck Aft Dry Lab	21 m2/ 226 ft2

Propulsion	Geared Diesel	**Propeller**	2 x Ducted Variable Pitch
Main Engines	2 x Bergen BRG-6		Ulstein 4 blades
	2650kw /3550 hp (each)	**Rudder**	2 x High Efficiency
Main Generators	2 x Shaft Generators		Becker Articulated
	1665 KVA each	**Seismic Air Source**	2 x Ariel JGK4
Harbor Generator	1 x Diesel Generator 720 kw	**Seismic Air Capacity**	2750 CFM @ 1950 psi each
Bowthruster	1 x Tunnel 590 kw/ 800 hp		

Ownership	The National Science Foundation
Operator	Lamont-Doherty Earth Observatory of Columbia University
Classification:	ABS- A-1, Ice Class 1C, AMS

SEISMIC INTERPRETATION SOFTWARE

NIU is equipped with several licenses for the Kingdom Suite from Seismic MicroTechnology. The licenses have been donated based on a five year basis. The total value of the licenses is approximately $200,000. As a backup the university also has OpendTect, a free seismic reflection interpretation software. It is expected that both of these pieces of software will be utilized in data analysis.

OTHER

Paleomagnetic, bathymetric, and gravity data will be available for future research for persons or organizations through databases such as NOAA and GEBSCO as well as being held at NIU. It is expected that the data will be used for future graduate and undergraduate research projects.

There are a number of software programs that may be purchased for university use however, paleomagnetic, gravity, and bathymetric interpretation are not at the forefront of this project. Therefore, purchasing of interpretation software is not requested at this time.